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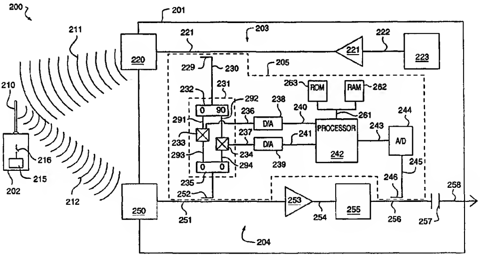

(57) Abstract

A system (150) for suppressing RF signals (211) transmitted by a transmitter (101) from the RF signals (212) received by a receiver (102). The RF signals transmitted by a transmitter are sampled by a coupler (107) of the system (150). The RF signals are then applied to a modulator (130) which adjusts the signals from the transmitter (101) to have an equal frequency and amplitude as the RF signals from the transmitter (101) as well as an opposite phase. The modulated signal is applied to the RF signals received by a receiver antenna (120). The modulated signals and signals from the transmitter cancel out which eliminates transmitter signals in the received signal. The resulting signal is monitored to determine the noise signals remaining in the received signal. The modulator is then adjusted to minimize the noise signals.

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A SYSTEM FOR REDUCING TRANSMITTER CROSS-TALK IN RECEIVE PART OF A RF TRANSCEIVER

Field of the Invention

This invention relates to a system having an RF transmitter proximate an RF receiver. More particularly, this invention relates to using a feed-forward RF signal to cancel out signals from the transmitter that are received by the receiver. Still more particularly, this invention relates to a system for modulating the feed-forward signal and applying the feed-forward signal to the received signals to cancel out noise signals cause by RF signals from the transmitter that are received by the receiver.

Problem

In today's society, there are many systems that transmit and receive Radio Frequency (RF) signals for communications purposes. It is common in such systems to have a transmitter proximate a receiver. One such system is a Radio Frequency Identification (RFID) reader system. RFID reader systems are used to identify objects in an area and to convey information about the objects. One example of an RFID system in use is an expressway toll charge system. In the expressway toll system, the RFID reader receives signals from a tag on a car as the car drives through a toll station. The tag transmits RF signals that identify the car passing through the toll station. The RFID reader identifies the car and either charges the account of the driver or verifies that the driver has prepaid a toll. Other future uses for RFID could include pay at the pump features for gas stations, and express checkouts in supermarkets.

One popular RFID reader system operates in the following manner. A RF transmitter transmits RF signals outward into the environment. The RF signals from the transmitter are unmodulated, continuous wave signals. The RF signals are received by antennas in any tag within the range of the transmitter. Tags are transceiver devices having antennas. However, the tags typically do not have many components of normal transmitters in order to reduce the cost per tag. For example, a tag typically does not contain a local oscillator or a power amplifier. Instead, the antenna in a tag is typically connected to a modulating device, such as a PIN diode,

which modulates RF signals to add information such as a User Identification to an RF signal.

When RF signals from the transmitter are received by the tag antenna, the antenna is illuminated and radiates a secondary or back-scatter RF signal. The back scatter signal is modulated by the modulating device connected to the antenna to carry information. Since the back scatter signal is a reflected signal, the signal tends to be weak.

A receiver in the RFID reader has an antenna that receives the back scatter signals and detects the modulated signals which are decoded by circuitry inside the reader. It is a problem that the receiver antenna also receives the RF signals from the transmitter. This is especially true when the receiver and transmitter are in close proximity to one another. The RF signals from the transmitter are many times stronger than the backscatter signals from the tag. Furthermore, the RF signals and the backscatter signals are about the same frequency. The stronger RF signals make the backscatter signals harder to detect by the receiver. The receiver must be designed to operate correctly despite the RF signals from the transmitter.

In order to avoid being saturated by the signals from the transmitter, a receive amplifier and a signal detector in the reader receiver must operate linearly. The result of linear operation of the amplifier and signal detector is that the transmitter signals appear as a DC voltage at the output of the signal detector. The DC voltage can be filtered by a capacitor. In order to operate linearly with both the high power transmitter signals and the weak backscatter signals, a high performance amplifier and detector are needed. The amplifier and detector are expensive circuitry that increases the cost of the receiver.

Even after this DC component corresponding to the carrier signal from the transmitter has been filtered, phase noise signals from the transmitter still remain in the signal received by the receiver. Phase noise signals are signals that result from small but unavoidable fluctuations produced in the local oscillator of the transmitter. The phase noise signals limit the performance of the receiver because as the backscatter signal from a tag gets weaker the noise to signal ratio of the backscatter signals degrades. The noise to signal ratio degrades until the signal can no longer be detected from the received signals.

One manner of eliminating the remaining phase noise is to use sub-carrier modulation techniques to modulate the back-scatter signals into sub-carrier frequencies. There is a need for a system that suppresses phase noise in the receiver after the signals have been received by the receiver and minimizes the required receiver dynamic range in order to minimize the cost of removing the noise from the received signals.

Solution

The above and other problems are solved and an advance in the art is made by the provision of a feed-forward system for reducing noise. Noise is hereinafter defined to include both carrier signal noise and phase noise in a receiver due to signals from a transmitter located proximate the receiver. The feed-forward system samples the signals generated by the transmitter and adjusts the sample signals to have a phase that is opposite of and a strength equal to the noise signals. The adjusted signals are then applied to the RF signals received by the receiver to cancel the noise signals caused by signals received directly from the transmitter. The desired signals in the received signals can then be more easily detected. The feed-forward system is cost effective since the system is added to the receiver instead of each tag used in the system.

The feed-forward system operates in the following manner in one preferred exemplary embodiment. A pick-off coupler captures a sample of the transmitted signals from the transmitter. The signals from the pick-off coupler are applied to modulator circuitry. The modulator circuitry adjusts the signals to cause the signals to have the same strength but opposite phase to the noise in the transmitted signals.

In a preferred exemplary embodiment, a vector modulator is used and the modulation circuitry includes a Quadrature modulator (Q-modulator) and an In-phase modulator (I-modulator). The signal from the transmitter is split into two signals. The signals are 90 degrees apart in phase. These two signals are then multiplied by a suitable constant by the Q-modulator mixing a Q-mod signal with a first signal from the transmitter and the I-modulator mixing a I-mod signal with the second signal from the transmitter. The resulting signals from the modulator are combined to form a signal that is opposite in phase and equal in amplitude to the signals from the transmitter.

The combined signals are then combined with the signals received by the receiver to suppress the signals from the transmitter that are received by the receiver.

The I-mod and Q-mod values may be at the time of installation or construction of the system to generate a constant signal. However, the amplitude and phase of transmitted signals may drift with time and the cancellation would become imperfect with the set values. In order to solve the problem of drift, the feed-forward system monitors the noise remaining in the received signals after the transmitter signals have been canceled out and adjusts the modulation of the feed-forward signals to suppress the remaining noise. This monitoring and tracking adjusts the signal to track temporal changes in the interfering signal. In the preferred exemplary embodiment, a DC voltage proportional to the remaining interfering signals is output from a detector. The DC voltage is applied to an analog to digital converter. The digital signal is monitored by a computer processing system which determines the amplitude and phase of the remaining interfering signals. The computer system then adjusts the I-mod and Q-mod signals transmitted from the computer to the modulator. The computer continuously monitors the noise signals and adjusts the I-mod and Q-mod signals to minimize the DC voltage.

Description of the Drawings

The above and other features of the present invention can be better understood from a reading of the detail description and the following drawings:

FIG.1 illustrates a diagram of a transmitter and receiver that incorporate the present invention;

FIG. 2 illustrates a block diagram of a preferred exemplary embodiment of an RFID system having the feed-forward cancellation system of the present invention; and

FIG. 3 illustrates a flow diagram of the operation of a monitoring processor in the preferred embodiment.

Detailed Description

A transmitter and receiver system having a feed-forward noise reduction - FIG.1.

FIG. 1 illustrates transceiver system 100 having a feed-forward noise reduction system of the present invention. Transceiver system 100 has a transmitter 101 and a receiver 102. Transmitter 101 is proximate receiver 102. Strong RF signals

transmitted by transmitter 101 are received by receiver 102 and interfere with the weaker RF signals that receiver 102 is attempting to detect.

Transmitter 101 is a transmitter commonly available to those skilled in the art. Transmitter 101 has a local oscillator 104 which generates RF signals and applies the signals to amplifier 103 via path 105. Amplifier 103 amplifies the signals and applies the signals to antenna 112 via path 106. The RF signals are then broadcast by antenna 112.

Receiver 102 is a receiver that is commonly available to those skilled in the art. Although receiver 102 may include other circuitry, those skilled in the art will understand the present invention from the represented components. Receiver 103 has an antenna 120 which receives RF signals broadcast by objects in the outside environment. The RF signals received by antenna 120 are applied to amplifier 122 via path 121. The amplified RF signals are then applied to detector 124 via path 123. Detector 124 is comprised of circuitry used to detected the desired RF signals that receiver 102 is designed to receive. Amplifier 122 and detector 124 are designed to operate serially to eliminate most signals directly transmitted from transmitter 101.

However, phase noise in the RF signals from transmitter 101 caused by oscillator 104 still remain in the signals received by receiver 102. The phase noise in the transmitted signals is represented as a DC voltage in the output of detector 104 which can be filtered by a capacitor. Therefore, the output of detector 124 is applied to capacitor 126 via path 125. Capacitor 126 filters the DC voltage from the detected signals. The detected signals are then applied to application circuitry (not shown) via path 127. The application circuitry (not shown) is circuitry that uses the detected circuitry to perform a function. The operational details of the application circuitry are unimportant in the context of the present invention.

The feed-forward system 150 of the present invention has a pick-off coupler 107 which receives RF signals being applied to path 106. The RF signals received by pick-off coupler 107 are applied to a modulator 130 via path 108. Modulator 130 is a commonly available modulator that can change the amplitude, and/or phase of RF signals. The RF signals received by modulator 130 are adjusted to have an amplitude equal to those signals being transmitted by transmitter 101. The adjusted

RF signals also have an opposite phase from the transmitted signals. The modulated signals are applied to coupler 137 via path 136.

Coupler 137 joins the adjusted RF signals with the signals received by receiver 102. The adjusted RF signals and the transmitted RF signals are of opposite phase with equal frequencies and amplitudes. The modulated RF signals cancel the RF Signals transmitted by transmitter 101 including any phase noise signals. The result is only desired signals received from objects other than transmitter 101 remain in the RF signals applied to detector 124.

Modulator 130 can adjust the signal to a constant phase and frequency by mixing the signals received from the transmitter with a constant signal provided by a local to provide a constant modulated RF signal. However, the transmitted RF signal may drift over time as wear changes the components of transmitter 101. However, the noise remaining in the signal may be detected from the DC current in the output of detector 124.

Monitor circuitry 132 can detect the noise remaining in the RF signals received by receiver 102 and adjust modulator 130 to remove the noise. The signals from detector 124 are received by a pick-off coupler 135 which applies the DC current to monitor circuitry 132 via path 133. Monitor circuitry 132 then determines the strength and phase of the remaining noise signals in the received signals. Monitor circuitry 132 then applies signals to modulator 130 via path 131 that adjusts the modulation of the feed-forward RF signals from transmitter 101 to cancel out the RF signals received from transmitter 101.

<u>A Preferred Exemplary Embodiment of an RFID Reader Containing the Noise Reduction Circuitry of the Present Invention.- FIG. 2.</u>

FIG. 2 illustrates a preferred exemplary embodiment of an RFID reader system 200 containing the noise reduction system of the present invention. An RFID reader system 200 is used to detect an identity of a tag in the area. The tag 202 is a transmitting device connected to an object to identify the object. For example, tag 202 may be connected to a car. Tag 202 identifies the car to pay a toll or to pay for gas at a gas station. Other uses include but are not limited to identifying animal in an area, credit card use, and price identification of merchandise in a store.

RFID system 200 has the following three components a transmitter 203, receiver 204 and tag 202. Transmitter 203 and receiver 204 are located in RFID reader 201. Tag 202 is located on an object in the operating environment. Only those elements essential to understanding the present invention are represented in FIG. 2. Those skilled in the art can and will design RFID systems 200 containing the feed-forward system 205 that will operate in the following manner.

Transmitter 203 contains a local oscillator 223 that generates continuous wave signals. The generated signals are applied to amplifier 221 via path 222. The amplified RF signals are now ready to be transmitted. The RF signals from amplifier 321 are strong continuous wave RF signals. Amplifier 221 applies the RF signals to antenna 220 which broadcasts RF signals 211 to the operating environment of RFID system 200.

RF signals 211 are received by antenna 210 in tag 202. Tag 202 is a tag inside the operating environment of RFID system 200. The RF signals received by antenna 210 illuminate antenna 210 causing the antenna to broadcast weak, back-scatter RF signals 212 outwards from tag 202. Circuitry 215 such as a pin diode is connected to antenna 210 via switch 216. When RF signals 211 are received, RF signals 211 are applied to circuitry 215 which modulates the signals to add information to the signals that are broadcast from antenna 210. The additional information can be but is not limited to identification, account balance, and operational information about the object. The modulated signals 212 are then broadcast by antenna 210.

Receiver antenna 250 receives RF signals 211 from transmitter 203 and RF signals 212 from tag 202. Since RF signals 211 are much stronger than RF signals 212 and at the same frequency as RF signals 212, RF signals 211 cause strong noise interference with RF signals 212 which makes it difficult to detect RF signals 212. The signals received by receive antenna 250 are applied to amplifier 253 via path 251. The amplified signals are then applied to detector 255 via path 254. Amplifier 253 and detector 255 are operated serially to minimize the effect of RF signals 211 on detecting RF signals 212. Detector 255 applies an output of RF signals to path 256. The noise from signals 211 from transmitter 203 is represented by a DC voltage on path 256. To eliminate the noise signals, capacitor 257 receives

the signals via path 256 and eliminates the DC current. The RF signals are then applied to operational circuitry (not shown) of RFID reader 201 via path 258.

Feed-forward system 205 operates in the following manner to cancel out RF signals 211 received by receiver antenna 250. Pick-off coupler 229 receives RF signal from amplifier via path 221. The signals received by pick-off coupler 229 are applied to modulator 231 via path 230. In modulator 231, the RF signals are split into first signals and second signals by splitter 232. The first and second signals are orthogonal in phase.

The first signals are applied to Q-modulator 233 via path 291 and the second signals are applied to I-modulator 234 via path 292. Q-modulator 233 adjusts the amplitude and frequency of the first signal by mixing the first signals with signals from path 236. I-modulator 234 adjusts the phase of the second signals by mixing the signals with signals from path 237. The resulting signals from Q-modulator 233 are applied to combiner 235 via path 293 and the resulting signals from I-modulator 234 are applied to combiner 235 via path 294. Combiner 235 joins the signals into a signal that is equal in frequency and amplitude and opposite in phase to the signals being transmitted by transmitter 203. The signals from combiner 235 are then applied to coupler 252 which joins the signals from combiner 235 with the signals received by receiver antenna 250. The joining of the signals from combiner 235 with the signals received by receiver antenna 250 cancels out the RF signals from transmitter 203.

It is possible to apply constant signals to path 236 and 237 to cancel out the expected RF signals that are expected from transmitter 203. However, over time the amplitude and frequency of RF signals transmitted by transmitter 203 may drift. Furthermore, the signals from transmitter 203 may contain phase noise caused by variations in the signals generated by oscillator 223. Although the phase noise may be different for every wave produced, it is known that adjacent wave contain similar noise. Therefore, monitoring the current phase noise being receive can be used to eliminate phase noise from subsequent signals.

In the preferred exemplary embodiment, the following monitoring components are added to account for drift and phase noise in the signal. All phase noise and signals from the transmitter that are not canceled out appear as a DC current in the output of detector. Pick-off coupler 246 receives the output of detector 255 via path

356 and applies the signal to Analog to Digital (A/D) converter 244 via path 245. The digital signals are then applied to processor 242 via path 243.

Processor 242 is a processing device capable of executing instructions to perform data operations. Machine read instructions for processor 242 are stored in Read Only Memory (ROM) 263 and/or Random Access memory (RAM) 262. Processor 242 reads from and writes to ROM 263 and Ram 262 via path 261. ROM is the memory containing operating instructions. RAM 262 contains data to perform the operations and may also contain instructions for operations to be performed. Processor 242 performs process 300 illustrated in FIG. 3 to monitor the noise in the received signals and the modulation of the signals to cancel out the noise.

Processor 242 applies Q-mod signals to a Digital to Analog convertor 238 via path 240. The converted Q-mod signals are then applied to Q-modulator 233 via path 236. I-mod signals are applied by processor 242 to D/A convertor 239 via path 241. The converted I-mod signals from D/A convertor 239 are applied to I-modulator 234 via path 237. The signals are adjusted by processor 242 to minimize noise by changing the modulation in Q-modulator 233 and I-modulator 234.

<u>Process for Monitoring Noise and Adjusting Modulation- FIG. 3.</u>

FIG. 3 illustrates process 300 which is the process used by the processor 202 in the RFID system 200 of the preferred exemplary embodiment to adjust the modulation of the modulated signal applied to the received signals. Process 300 begins in 301 by sampling the resulting noise signal after the received signals have been applied to detector 255. In step 302, the I-mod signals transmitted by processor 242 are adjusted. This is done by adjusting the phase of the I-mod signals. In step 303, the resulting noise signal is sampled after the I-mod adjustment has been made to the modulated signals from modulator 231. Processor 242 then determines if the noise has been minimized below a certain level in step 304. If the noise signals have not been minimized beyond a certain level, steps 301 to step 304 are repeated.

Once the noise has been minimized to a predetermined level by adjusting the I-mod signal, the Q-mod signal is adjusted. The Q-mod signal adjustment begins in step 305 by sampling the output of detector 255. The amplitude and frequency of Q-mod signals are adjusted in step 306. In step 307, the noise signal output by detector 255 is sampled to determine how much noise remains in the signal. In step 308, it is

determined whether the noise signal has been minimized to a predetermined level. If the noise signal has not been minimized steps 205 to 208 are repeated. If the noise has been minimized, process 300 begins again at step 301. By looping through process 300 continually, processor 242 is able to maintain the noise signal to a predetermined level.

The above is a description of a system that uses feed-forward signals to cancel out RF signals received by a receiver from a connected transmitter. Those skilled in the art can and will design alternative feed-forward systems that infringe on the invention as set forth in the claims below either literally or through the Doctrine of Equivalents.

What is claimed is:

1. A system (150) for reducing interference in a RF signal receiver (102) from RF signals transmitted from a transmitter (101) proximate to said receiver(102) comprising:

a pick-off coupler (107) for receiving RF signals generated by said transmitter (101);

modulator circuitry (130) that adjusts said RF signals from said transmitter (101) to be substantially equal in amplitude and substantially opposite in phase to an interference RF signal received by said receiver (102) from said transmitter (101); and

an injection coupler (137) that applies adjusted RF signals to RF signals received by said receiver (102) to cancel out said interference signals.

2. The system of claim 2 further comprising:

interference signal detection circuitry (132) for detecting said interference signals.

3. The system of claim 2 wherein said interference detection circuitry determines the amplitude and phase of said interference signals.

4. The system of claim 3 further comprising:

modulation control circuitry (132) that adjusts RF signals applied to said modulator circuitry (130) to suppress said interference signals.

5. The system of claim 1 further comprising:

a pick-off coupler (246) in said receiver that receives said interference signals from a detector (255) in said receiver;

an analog to digital converter (244) that converts said interference signals from analog RF signals to digital signals;

a processing system (242) that executes applications which monitor the amplitudes and phase of said interference signals and adjust the amplitude and phase of signals applied to said modulator circuitry (130) to adjust the amplitude and phase of said adjusted signals to connect with said interference signals.

6. The system of claim 5 wherein said modulator comprises:

a splitter (232) that splits said RF signals from said transmitter (101) into a first signal and a second signal having substantially equal amplitude and 90 degrees apart in phase;

a Q-modulator (233) which receives a first of said separate signals and combines said first signal with a first received signal;

an I-modulator (234) which receives a second of said separate signals and combines said second separated signal with a second received signal; and

a combiner (235) that combines resulting signals from said I-modulator (234) and said Q-modulator (233) into said modulated RF signals;

7. The system of claim 6 wherein said processing system (242) transmits said first received signal and said second received signal, said system further comprising:

a first digital to analog converter (238) that converts said first received signal transmitted by said processing system (242) into analog signals and applies said signal to said Q-modulator (233); and

a second digital to analog converter (239) that converts said second received signal transmitted by said processing system (242) into analog signals and applies said second received signal to said I-modulator (234).

8. The system of claim 5 further comprising:

instructions (300) for directing said processing system (242) to determine a setting of said first received signal for said Q-modulator (233), to determine a setting for said second received signal for said I-modulator (234), to transmit said first and said second received signal to said modulator circuitry (130); and

a computer readable media for storing said instructions.

9. The system of claim 5 further comprising:

a capacitor (257) that receives signals from said detector (255) and filters noise signals from said signals received by said receiver.

10. A method for reducing interference in a receiver (102) from RF signals transmitted by a transmitter (101) proximate said receiver comprising the steps of:

receiving RF signals generated by said transmitter (101);

adjusting said RF signals from said transmitter to be substantially equal in amplitude and substantially opposite in phase to interference signals received from said transmitter (101) by said receiver (102); and

applying adjusted RF signals to RF signals received by said receiver (102) to suppress out said noise signals.

11. The method of claim 10 further comprising the steps of:

detecting interference signals in RF signals received by said receiver (102).

12. The method of claim 11 further comprising the steps of:

determining the amplitude and phase of said interference signals responsive to detecting said noise signals.

13. The method of claim 12 further comprising the steps of:

adjusting said modulated signals to cancel said interference signals.

14. The method of claim 10 further comprising the steps of:

receiving interference signals from a detector in said receiver;

monitoring the amplitudes and phase of said interference signals; and

adjusting the amplitude and phase of signals applied to said modulator to adjust the amplitude and phase of said modulated signals.

15. The method of claim 10 wherein said step of modulating comprises the steps of:

splitting said RF signals from said transmitter into a first signal and a second signal having substantially equal phases and 90 degrees apart in phase;

modulating said first signal;

modulating said second signal; and

combining resulting first and second signals to produce said modulated RF signals.

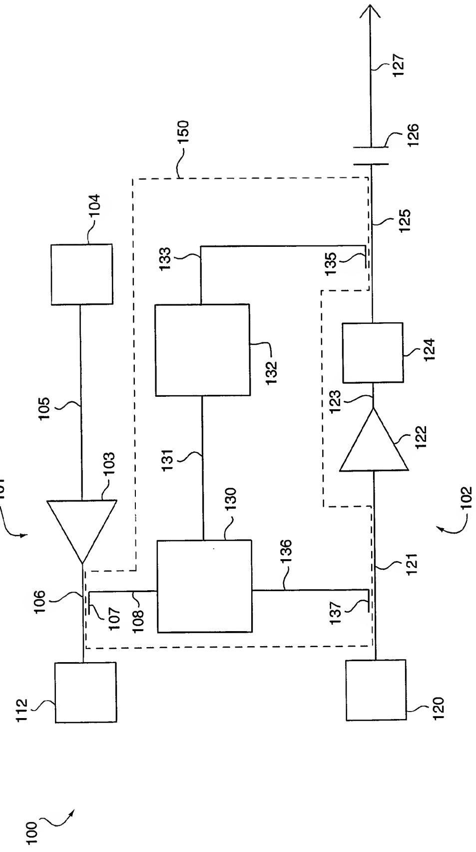
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FIG. 1

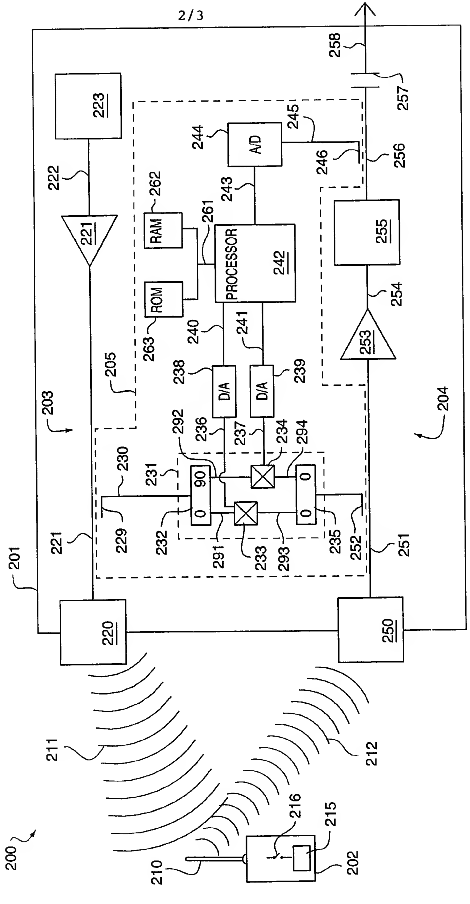
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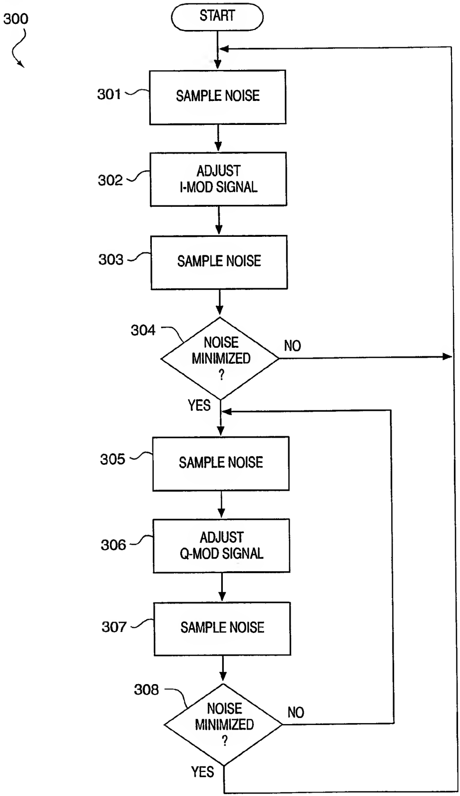
FIG. 2

FIG. 3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INTERNATIONAL SEARCH REPORT

Inter. ıal Application No
PCT/US 99/23084

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According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H04B G01S

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X A	US 5 140 699 A (KOZAK JOHN P) 18 August 1992 (1992-08-18) abstract column 2, line 55 -column 9, line 40 page 1 ---	1-4, 10-13,15 5-9,14
X A	US 3 696 429 A (TRESSA FRANK J) 3 October 1972 (1972-10-03) the whole document ---	1-4, 10-13,15 5,6,14
A	GB 2 300 318 A (PLESSEY CO LTD ;SIEMENS PLESSEY ELECTRONIC (GB)) 30 October 1996 (1996-10-30) abstract page 1, line 1 -page 5, line 19 figure 1 -----	1-6, 9-12,14

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Date of the actual completion of the international search	Date of mailing of the international search report
12 January 2000	20/01/2000

Name and mailing address of the ISA	Authorized officer
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INTERNATIONAL SEARCH REPORT

Information on patent family members

Inter nal Application No
PCT/US 99/23084

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